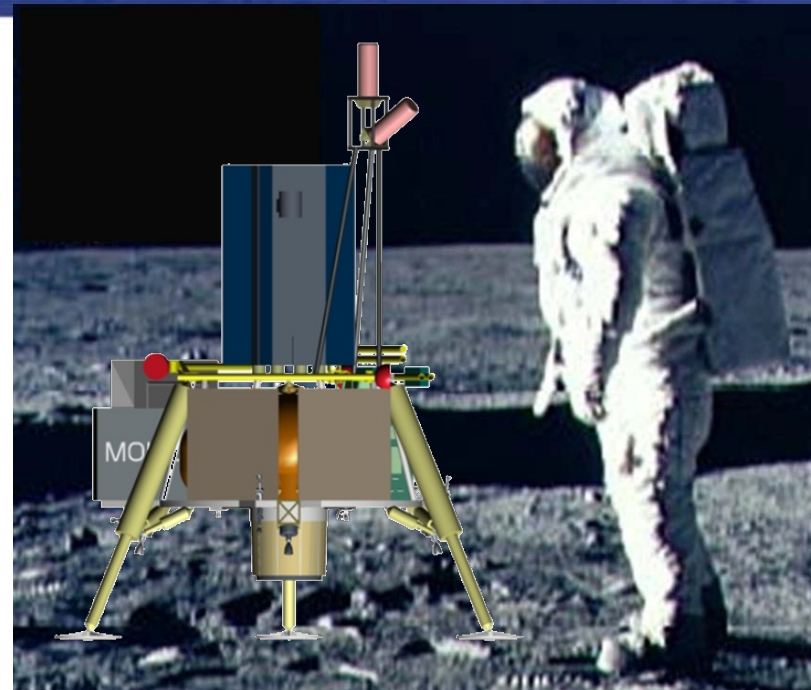
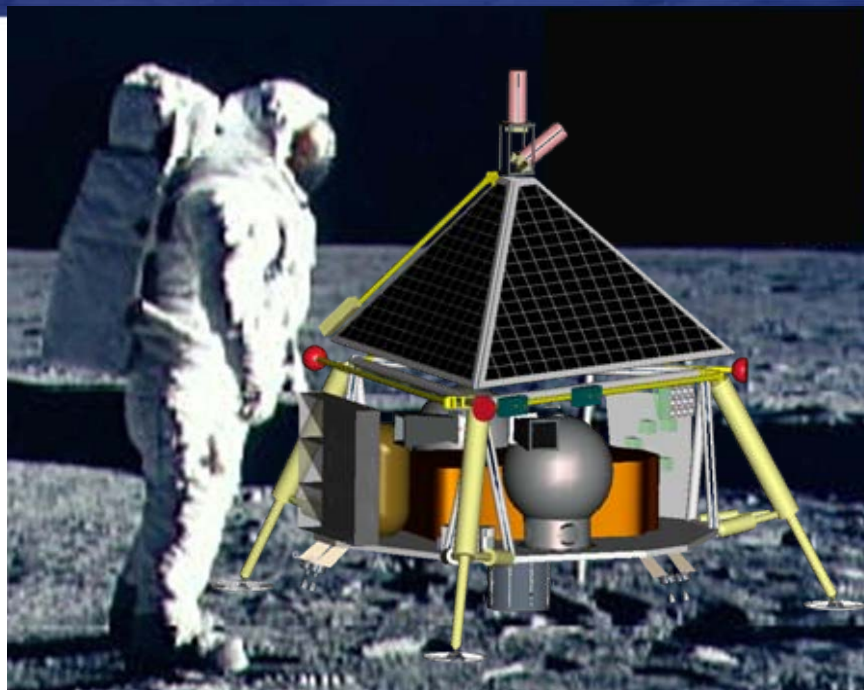


# Robotic Lunar Lander Development Project Status



## *Project Description*

*Lunar Science mission in pre-formulation performing engineering tests and risk reduction activities to support the development of a small lunar lander for lunar surface science.*

*March 1, 2010*

# Flight Robotic Lander Risk Reduction

**Performing extensive engineering analyses and tests to reduce risk in the development and implementation phases of the project**

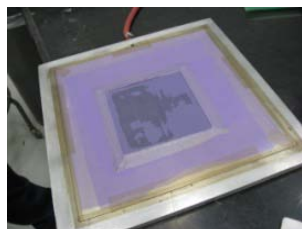
- **Robotic Lander Test Bed:** Hardware in the Loop (HWIL) testing with landing algorithms and thruster positions
- **GNC Test Bed:** Closed-loop, real-time bench testing with the integrated development and test system.
- **GN&C:** validation of landing algorithms with simulations and HWIL
- **Propulsion:** thruster testing in relevant environment, pressure regulator valve performance characterization in relevant environment
- **Thermal:** variable heat transport and lunar heat rejection testing
- **Structures:** composite coupon testing, lander leg stability testing
- **Power:** thermal and life battery testing
- **Avionics:** testing of a low power, high speed communications, and large data storage capacity processor



**LN-200S IMU**



**Radar  
Altimeter**





# Incremental Development Approach for Flight Robotic Lander Design: Phase 1 (Cold Gas)



## Robotic Lander Testbed - Cold Gas Test Article (Operational)

- Completed in 9 months
- Demonstrates autonomous, controlled descent and landing on airless bodies
- Emulates robotic **flight** lander design for thruster configuration in 1/6<sup>th</sup> gravity
- Incorporates **flight** algorithms, software environment, heritage avionics, and sensors
- Gravity cancelling thruster provides for reduced gravity operations that can vary with throttling
- Flight time of 10 seconds and descends from 3 meters altitude
- Utilizes 3000psi compressed air for safety, operational simplicity, and multiple tests per day
- 3 primary and 3 ACS thrusters

**Robotic Lander Testbed - Cold Gas Test Article available now to International Partners and industry for hardware demonstration, software and model validation or technology testing**

*Provides a platform to develop and test algorithms, sensors, avionics, and systems to support autonomous landings on airless bodies, where aero-braking and parachutes are not options (e.g. the moon, asteroids)*

# Cold Gas Test Article in Flight Demonstration Testing



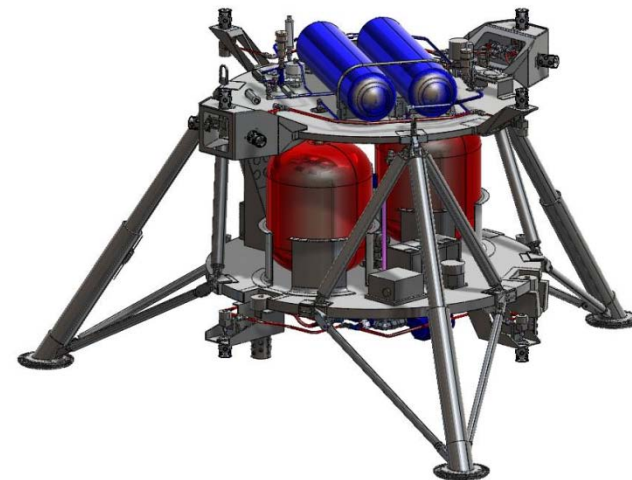
*Test bed provides for **autonomous closed loop** control to demonstrate landing capability on airless bodies to build confidence and reduce overall risk.*



# Incremental Development Approach for Flight Robotic Lander Design: Phase 2 (Warm Gas)

## Warm Gas Test Article (Summer 2010) adds to Cold Gas Test Article Functionality:

- Began WGTA September 2009 ; Completed Critical Design Review March 2010
- Designed to emulate Robotic **Flight** Lander design sensor suite, software environment, avionics processors, GN&C algorithms, ground control software, composite decks and landing legs
- Longer flight duration (approx. 1 min) and descends from 30 meters to support more complex testing
- Can accommodate 3U or 6U size processor boards.
- Incorporates cFE which allows for modular software applications , including GNC, for ease of integration and test.
- 12 thruster ACS configuration. Option to only fire 6 ACS thrusters. Provides capability to support testing of hazard avoidance or precision landing algorithms. Emulates pulse or throttle system.
- G-thruster can be set to different g levels between 1 g to zero g for descent. Therefore, can be used to emulate any airless body for descent.



**Robotic Lander Testbed - Warm Gas Test Article available in 2011 to International Partners and Industry for hardware demonstration, software and model validation or technology testing**

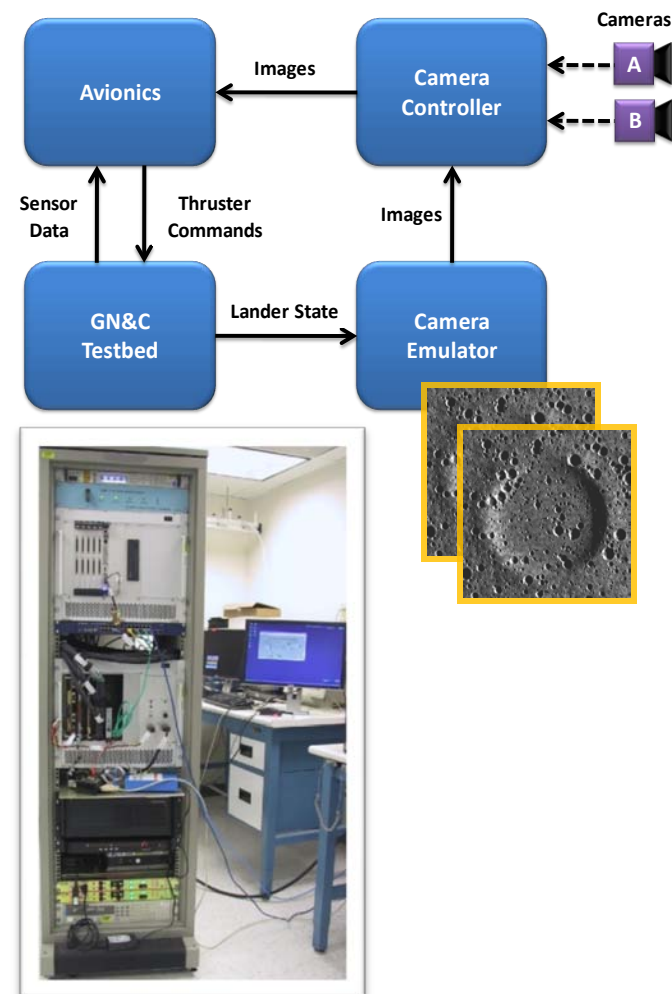
*Provides a platform to develop and test algorithms, sensors, avionics, software, landing legs and integrated system to support autonomous landings on airless bodies, where aero-braking and parachutes are not options*

# Flight Software: Incremental Approach to Developing and Testing Landing Algorithms

**Development and testing of software for real-time Guidance Navigation & Control Landing algorithms reduces risk for flight Robotic Lander:**

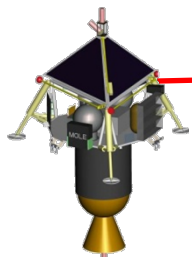
- Integrated system for development and testing of real-time lander GN&C software:
  - Develop embedded software for GN&C algorithms designed for descent and landing.
  - Develop and incorporate real-time image processing algorithm to support nulling lateral motion during descent.
  - Execute and test the embedded software in a flight-like avionics processor, characterize performance.
  - Develop GN&C testbed hardware/software that monitors thruster commands from the avionics flight software, models lander dynamics, and injects real-time simulated sensor data and images into the avionics.
  - GN&C testbed includes camera controller and camera emulator to support evaluating cameras and simulating lunar images.
- Three phases of testing lander GN&C software:
  - Closed-loop, real-time testing with the integrated development and test system.
  - Flight testing of GN&C and image processing algorithms with Warm Gas Test Article.
  - Field tests with cameras and camera controller to test image processing algorithm with high rates of lateral motion.

## Integrated Development and Test System



# Flight GNC: Incremental Development Approach for Validating Algorithms thru Analysis and Test

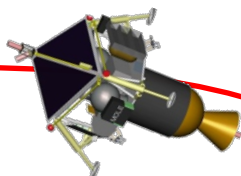
## Cruise



Slow spin, 6 RPM  
Spin axis normal to ecliptic

***Tested by closed-loop simulation (typical for other missions)***

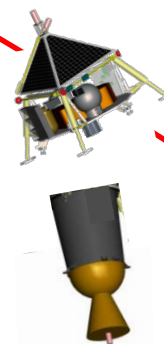
## Braking Burn



Initial Altitude: 16.6 km  
Final Altitude: 3 km  
Initial Velocity: 2.5 km/s  
Final Velocity: 0.105 km/s  
Initial Mass: 1136.6 kg  
Final Mass: 456 kg

***Tested by closed-loop simulation, numerous Monte Carlos***

## Descent



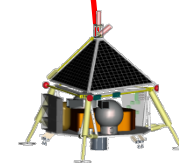
Initial Altitude: 3 km  
Initial Velocity: 0.105 km/s  
Initial Mass: 380.6 kg

***Tested by closed-loop simulation and high velocity field test 2011***

## Terminal Descent

***Tested by closed-loop simulation and with Cold Gas and Warm Gas Test articles for HIL closed-loop testing (2009-2010)***

Final Mass: 343.5 kg  
Touchdown Vel.: < 1 m/s





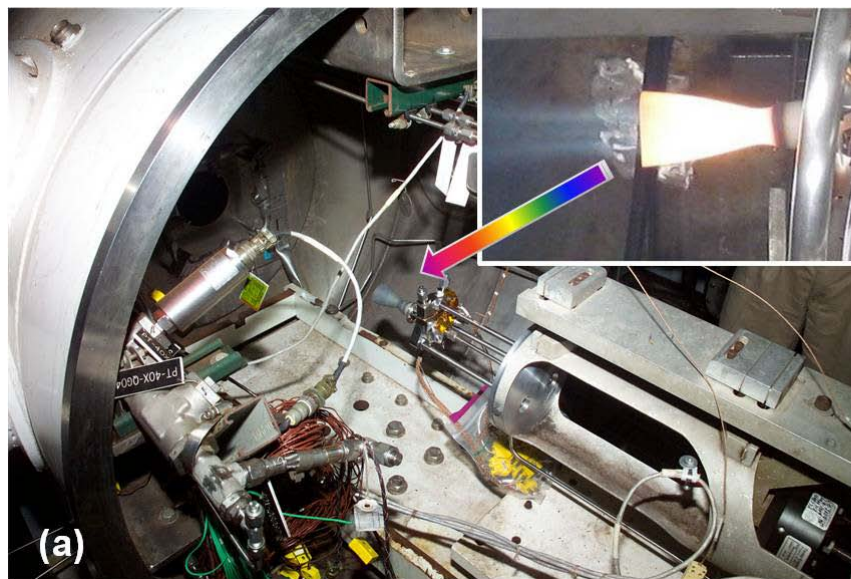
# Flight Propulsion System Risk Reduction Tests

- **Flight Robotic Lunar Lander Thruster Hot-Fire Tests**

- On September 15, 2009, MSFC completed a matrix of 12 hot-fire tests one week ahead of schedule
- The test included a mission profile representing a lunar lander duty cycle. This profile spanned 995 seconds and included pulses, coasts, and steady-state burns.
- The test program fully accomplished its objectives, including evaluation of combustion stability, engine efficiency, and the ability of the thruster to perform a lunar lander duty cycle.
- Figure (a) is the Test Setup in Vacuum Chamber at White Sands Test Facility for DACS Thruster Hot-Firing and Comparison of Engine Envelope.
- Figure (b) is a conventional (LEROS 2B) Thruster and figure (c) is the DACS Thruster developed by the Missile Defense Agency
- Additional tests planned for July 2010

- **Pressure Regulator Testing**

- Objective of the regulator test is to assess the ability of an available heritage regulator to meet the ILN mission requirements. The regulator is an unmodified commercial unit.
- Test activities have already begun and will be completed by June 2010.





# Flight Thermal Management Testing

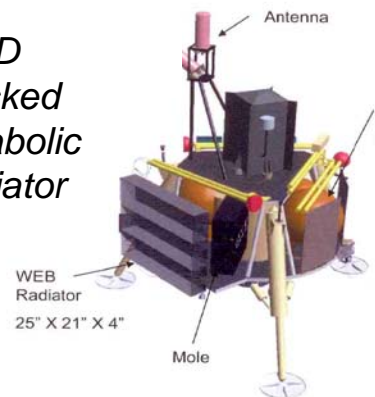
## Compact radiators that reject lander waste heat during hot lunar noon thermal conditions

- Lunar surface temperatures as high as 390K
- Unknown landed attitudes and surface topology; radiator views of hot regolith and the sun
- Lunar dust degradation of radiator optical properties
- Completed thermal performance analysis of standard and novel radiators, locations/orientations and enhancements and key sensitivities. Two baseline options beginning prototype radiator fabrication.
  - Horizontal flat radiator with removable, protective dust cover
  - Stacked, vertical parabolic, radiator with attitude adjustment capability



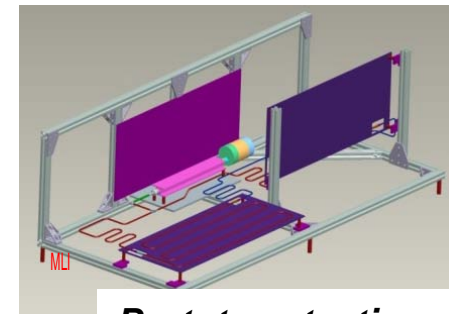
ALSEP Magnetometer Stacked Parabolic Radiator

*RLLD  
Stacked  
Parabolic  
Radiator*



## Passive, variable conductance heat transport capability that thermally couples/decouples the main electronics compartment with heat rejection radiators

- ~5kg of power system mass for each watt of heater power required during lunar night
- Shadows ranging from 14 earth days to permanent
- Lunar surface temperatures from 100 – 390K
- Concept studies at multiple suppliers examined various thermal switch/transport technologies.
- Two loop heat pipe concepts and one variable conductance heat pipe concept selected for fabrication & testing



*Prototype testing*

